

PATENT

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APPLICATION FOR UNITED STATES LETTERS PATENT

for

APPARATUS AND METHOD FOR RAPID FAULT DETECTION AND
TRANSFER IN A UTILITY-INTERACTIVE UNINTERRUPTIBLE POWER SUPPLY

By

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CROSS REFERENCE TO RELATED APPLICATION AND PRIORITY CLAIM

This application claims the benefit of Provisional U.S. Patent Application Serial No. 60/208,617, entitled "Apparatus And Method For Rapid Fault Detection And Transfer In A Utility-Interactive Uninterruptible Power Supply", naming the same inventors as identified herein and filed June 1, 2000.

BACKGROUND OF THE INVENTION

The double conversion topology has been the uninterruptible power supply (UPS) standard for high performance topologies for the last 30 years. Double conversion provides the ultimate isolation of the critical load from the anomalies present on the utility electric lines. Some drawbacks of the double conversion topology are that the input rectifiers tend to draw currents at poor power factors and also tend to introduce harmonics, and performance is inconsistent throughout the load range. Filters improve the performance of double conversation systems but do not remedy it.

Recently, another topology has been presented for use as a high performance topology suitable for critical loads. The utility interactive topology does indeed have appeal as it provides the ideal load to the utility, drawing power at near unity power factor and at low harmonic distortion throughout its load range. Additionally, utility interactive topologies exhibit greater efficiencies than the classic double conversion topologies for certain load types. On the downside, utility interactive topologies do not protect the critical load as well from utility line anomalies. Among other shortcomings, certain types of utility faults will pass through the utility interactive system and disturb the critical load. The occasional passing through of utility line faults with this topology is due to the inability of the input coupling switch to disconnect in a quick enough fashion. Ordinary inverse-parallel connected thyristors are often used for this purpose due to their characteristics that make them very well suited for this application. Unfortunately, one

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drawback of thyristors is that they cannot achieve the off or blocking state without having the applied current achieve a zero value.

SUMMARY OF THE INVENTION

An object of the present invention is to ameliorate the system output waveform disruptions that occur due to input utility line disturbances. The pass through of disturbances that can not be sufficiently attenuated by the normal operation of the utility interactive power converter can only be stopped by rapid disconnection of the input coupling switch means. Two techniques are disclosed that accomplish this. The first technique is suitable for use with switches that require the current to achieve zero for commutation, such as thyristors—Silicon Controlled Rectifiers (SCRs), for example. This technique operates one or both of the inverters in such a manner to cause the line current to achieve zero value in a time period during which the net output disturbance is of little concern. The second technique uses a switch that can be self commutated or uses a non self-commutating switch with auxiliary commutation circuit elements. Also disclosed are several variations of a voltage clamping scheme that is required to deal with the energy released by the line circuit inductances during commutation.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a high level block diagram of a typical offline UPS.

Fig. 2 is a high level block diagram of a typical line interactive UPS.

Fig. 3 is a high level block diagram of a typical online, double conversion UPS.

Fig. 4 is a high level block diagram of a delta conversion UPS.

Fig. 5 is a one-line diagram of a line interactive, delta conversion UPS employing a naturally commutated fast utility disconnect switch in accordance with the present invention.

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Fig. 6 is a one-line diagram of a line interactive, delta conversion UPS employing a self commutated fast utility disconnect switch and one alternative snubber circuit in accordance with the present invention.

Figure 7 is a one-line diagram of a line interactive, delta conversion UPS employing a self commutated fast utility disconnect switch and another alternative snubber circuit in accordance with the present invention.

Figure 8 is a one-line diagram of a line interactive, delta conversion UPS illustrating connection of a current or voltage sensor used in control of the fast utility disconnect.

Figure 9 is a one-line diagram of a line interactive, delta conversion UPS employing a self commutated fast utility disconnect switch and another alternative snubber circuit in accordance with the present invention.

Figure 10 is a one-line diagram of a line interactive, delta conversion UPS employing a self commutated fast utility disconnect switch and another alternative snubber circuit in accordance with the present invention.

Figure 11 is a one-line diagram of a line interactive, delta conversion UPS employing a self commutated fast utility disconnect switch and another alternative snubber circuit in accordance with the present invention.

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The mission of an uninterruptible power supply (UPS) is to protect a critical load from all power disturbances present on the utility power grid. The UPS accomplishes this result by providing a steady, continuous power supply. Several types of utility

1 disturbances are commonly found, including transients, sags, surges, brownouts,
 2 blackouts and faults.

3 Utility faults are short circuits that occur when a phase line is inadvertently
 4 connected to a neutral (or ground) or to different phase line. Fault conditions can occur
 5 anywhere in a power grid, and may be caused by auto accidents, lightning, activities in-
 6 plant or within neighboring or remote plants.

7 In the case of phase-to-neutral faults, the phase and neutral voltages will move
 8 close together. This will last for a limited period of time and then be terminated by an
 9 upstream overcurrent protective device opening at least the faulted phase. Because of the
 10 massive energy concentration at the fault, the fault may disconnect itself before any
 11 protective action. It should be noted that no matter what happens, all the downstream
 12 loads remain connected. Consequently, during the fault the UPS feeder remains in a low
 13 impedance state and appears as a short circuit. Open circuit, high impedance utility
 14 failures are unusual.

15 In the case of phase-to-phase faults, a shorted condition causes both phase
 16 voltages to move together and behave as one. This presents an apparent phase shift and
 17 an averaging of the voltages. As before, the fault may clear itself. If a circuit breaker is
 18 upstream of the fault then all three phases could open, likely in an erratic fashion because
 19 of arcing in the breaker. If fuses are upstream of the fault then other possibilities exist.
 20 The shorted phases may both open or one of the two phases may open.

21 The simplest type of UPS is the off-line topology, shown in Figure 1. Under
 22 normal operating conditions, AC power from the utility passes from the input 101 straight
 23 through the UPS to the critical load connected to output 107. A charger 102 or "4-

1 their output phase angle. Because the phase angle cannot be shifted quickly without
2 potential disruption of the critical load the difference in power required to compensate for
3 the disturbance is extracted from the battery 204. The resulting frequent hits on the
4 battery shorten battery life. Another limitation of line interactive products is that they
5 cannot completely isolate the critical load from the input line without operating on
6 battery power. Small frequency perturbations and power quality disturbances get passed
7 directly to the critical load. Without electrical isolation, common-mode noise also passes
8 right through the UPS to the critical load.

9 The premium UPS topology is the true on-line or double conversion UPS
10 illustrated in Figure 3. Input 301 is connected to rectifier 301, which rectifies incoming
11 AC power to DC power to supply the internal DC bus 308 of the UPS. Output inverter
12 304 takes the DC power from DC bus 308 and produces AC power to support the critical
13 load connected at output 307. Battery 303 is attached to DC bus 308 and is float charged
14 during normal operation. When the input power is out of the tolerance limits, battery 303
15 provides power to support inverter 304 and the critical load. Some advantages of this
16 configuration include: load isolation, output voltage stability, output voltage and
17 frequency independence, capability for separate inputs for the normal and bypass source,
18 backfeed prevention, and mature and well-understood technology.

19 The traditional double conversion online UPS is designed to operate despite any
20 type of utility line fault or other utility line disturbance. This operation results because
21 the input rectifier 302 chops up the incoming utility voltage and turns it into direct
22 current (DC) voltage for the battery 303. Within reason, battery 303 can tolerate minor
23 disruptions on the energy supply.

The steady DC voltage produced by rectifier 303 or battery 303 is used to power output inverter 304. The inverter creates a completely new waveform for the critical load connected at output 307. In the double conversion online UPS the critical load output waveform has no necessary relationship to the incoming utility waveform. Consequently the output waveform remains independent of utility waveform disturbances.

The intermediate DC link between the input rectifier and the output inverter (i.e., DC bus 308) provides filtering and short term energy storage. A battery connection at this point provides longer term energy storage, enabling the UPS to ride through more significant utility line disturbances. Consequently, incoming line disturbances (other than long-term blackouts) have no effect on the critical load. Input faults are not a problem for double conversion UPS products. Input rectifier 302 only allows power flow in one direction, so an input line fault merely causes the unit to operate on battery power.

One type of line interactive UPS is the delta conversion UPS, illustrated Fig. 4. The delta conversion UPS is a line-interactive UPS in the classic sense, meaning that the series transformer 403 and output inverter 406 interact with the incoming utility voltage to alter the output voltage. This topology has a small input buck/boost inverter 404 that modifies the input voltage. This small inverter 404 is referred to as a series inverter because it theoretically only processes the difference (the delta) between the actual input waveform and the "ideal" output waveform. The series inverter attaches to the DC bus 409, which it uses as a pipeline to exchange power with the output (main) inverter 406. Because the series inverter processes only the power difference in either direction, it is typically rated only for a small portion, e.g., 20%, of the rated UPS output.

In the normal mode (which means a nominal input waveform and a linear load on UPS), the utility disconnect static switch 402 is closed. Utility power is therefore supplied directly to the output 408.

When the input voltage is present but not at its nominal value, series inverter 404 injects a voltage into buck/boost transformer 403 to add or subtract from the input voltage. This creates a regulated output voltage, similar to some electronic voltage regulators.

When the input power goes out of tolerance limits, main inverter 406 will supply full output power. The utility disconnect static switch 402 is turned off to prevent backfeeding. Power failures that will activate main inverter 406 include the input voltage going outside the regulation range of series inverter 404 and deviations of the input power source frequency or phase angle.

Providing load harmonic current and power factor correction requires that main inverter 406 operate to inject the required compensation currents, either harmonic currents and fundamental frequency reactive currents. Series inverter 404 operates to correct the voltage. The function of the inverter in normal operation is to stabilize the output voltage and to supply reactive or harmonic power if so required by the load. The amplitude and phase of the main inverter 406 can be controlled as to maintain the desired state of charge on the battery and thereby compensate for the power flow to or from the series inverter.

Like the offline UPS, the line interactive UPS can be efficient because it supports the entire critical load only during power disturbances. Compared to the offline UPS, the

line interactive UPS pays a small efficiency penalty for the series inductor (or transformer) 403 and for losses associated with their power conditioning functions.

Line-interactive and offline UPS products are notoriously susceptible to input faults, which is why they typically have a utility disconnect static switch and fast blowing fuses on the input, attempting to prevent feeding power from the DC bus back to the utility. In a utility interactive UPS the utility waveform is used as the foundation to construct the output waveform. The utility interactive UPS makes modifications to the raw utility waveform to make that utility waveform more suitable as an output waveform for the critical load. For instance, if the incoming voltage is too low, voltage is added to raise the output voltage to the proper level. Similarly, incoming voltage that is too high is reduced. Harmonics are subtracted from the input to present a cleaner sine wave at the output.

At first appearance this method seems to provide a high-efficiency, utility-friendly means to present a quality waveform to a critical load. It is very important, however, to recognize the limitations of this system. Because the output critical bus waveform is constructed from the utility sinewave, frequency independence is impossible without battery operation.

An analysis of a typical utility interactive UPS design illustrates that utility waveform corrections up to 20% of the input voltage can be made. The limit employed in such a system is arbitrary, and is typically chosen with cost in mind. For disturbances beyond the 20% limit, the UPS must disconnect the utility input and run on battery power. Under certain utility conditions, this results in repeated battery hits that shorten battery life. To compound the problem, under some utility conditions the UPS cannot

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1 disconnect the utility to shield the critical load from the disturbance. The present
2 invention is directed to a solution to this second problem.

3 A utility interactive UPS must respond immediately and correctly to utility faults
4 and other disturbances if the critical load is to receive quality output power. The control
5 system must detect and analyze the disturbance, determine the appropriate response, and
6 correct the utility waveform, all in sufficient time to keep the utility line disturbance from
7 disrupting the critical load. Many utility disturbances occur very quickly placing severe
8 design requirements on control and inverter performance.

9 Because the utility waveform must be corrected in real time, the input and output
10 inverters and the rest of the power transfer system in the line interactive UPS must
11 exhibit much higher performance than their counterparts in a double conversion online
12 UPS. The control systems employed in utility interactive systems must make high-speed
13 decisions not required of the traditional online UPS controllers. Because of technological
14 limitations, disturbances that would be easily and intrinsically blocked by online systems
15 will, in some cases, pass right through utility interactive systems, disrupting the critical
16 load. Attempts to reduce pass through increases the complexity of utility interactive
17 systems and may actually lower the overall expected reliability.

18 The ability of certain utility faults to propagate through the utility interactive UPS
19 to the critical load is a result of its topology. For the output of the utility interactive UPS
20 to remain undisturbed during significant utility disruptions, the utility must be
21 disconnected and the critical load supplied by the battery via inverter operation. The
22 limited ability to disconnect the utility during faults is a fundamental weakness of the
23 prior art utility interactive UPS designs.

The typical prior art line interactive UPS, as illustrated in Fig. 2, has a utility disconnect 205, which is not self commutated and it does not ensure that inverter 203 is disconnected from input 201 quickly in the event of a fault. Certain types of faults, particularly line-to-line faults, can cause connected at output 207 the inverter fuses to blow. This unavoidably de-energizes the critical load, because the unit has no separate bypass line to which it can transfer. In other situations, the input fuses might blow, forcing the UPS to switch to battery power before eventually dumping the critical load.

While the propagation of certain utility faults and transients is typical of prior art utility interactive UPS designs, a solution is possible. A fast-utility-disconnect may be used in place of the common utility disconnect switch. The fast utility disconnect is a solid state static switch that rapidly disconnects the faulted input from the UPS and the critical load. The fast utility disconnect may be naturally commutated or self commutated. A naturally commutated utility disconnect may be constructed from thyristors, e.g., Silicon Controlled Rectifiers ("SCRs"), connected in anti-parallel. A self commutated fast utility disconnect may be constructed from transistors, such as insulated gate bipolar transistors ("IGBTs") or metal oxide semiconductor field effect transistors ("MOSFETs"), or other gate commutated switching devices. A fast utility disconnect may also be constructed from self commutated thyristors. If a self commutated fast utility disconnect is used, additional clamping circuitry is required. Descriptions of both embodiments follow below.

A simplified schematic of a utility interactive UPS employing one embodiment of the present invention is illustrated in Fig. 5. The illustrated circuit is a single phase circuit, but the invention and principles described below are equally applicable to a three

1 phase circuit. Alternating current (“AC”) power is received at input 501. The critical
2 load to be powered is connected to the UPS at output 515.

3 During normal operation, AC power passes through a naturally commutated fast
4 utility disconnect 502. The fast utility disconnect is comprised of two silicon controlled
5 rectifiers (“SCRs”) 502a and 502b connected in anti-parallel. In a three phase system,
6 each phase of the fast utility disconnect would comprise a pair of anti-parallel-connected
7 SCRs. The SCRs are gated to allow power to pass from input 501 to low-pass filter 503,
8 which serves to provide some conditioning of the incoming voltage. Low-pass filter 503
9 is a second order filter comprised of inductor 504 and capacitor 505. Other filter designs
10 which are well known to those of ordinary skill in the art may also be used.

11 AC power to be delivered to the critical load then passes through one winding of
12 transformer 506, which is connected in series with the UPS bus 56. The purpose of
13 transformer 506 will be discussed in more detail below. The power for the critical load
14 then passes to the critical load by way of capacitor 514, which serves as a filter capacitor
15 to reduce small high frequency components on the output waveform and also serves to
16 minimize the effects of load transients on the output voltage.

17 The second winding of transformer 506 is connected to inverter 507, which is
18 called a “series inverter” Series inverter 507 is comprised of switching devices 507a and
19 507b, which are typically power transistors. In a three-phase system, six switching
20 devices would be used, two per phase. One purpose of series inverter 507 is to make up
21 any difference between the desired voltage at UPS output 515 and the voltage supplied at
22 input 501. Inverter 507 also controls the input power factor of the UPS by drawing
23 current from input 501 that is sinusoidal and in phase with the input voltage. Inverter

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1 507, in conjunction with inverter 511, is also used to maintain the charge on battery 508.
2 General principles related to design of such inverters and their controllers are well known
3 to those of ordinary skill in the art.

4 The voltage generated by series inverter 507 is impressed between positive DC
5 voltage rail 509a and negative DC voltage rail 509b, which serve as the DC bus for the
6 UPS system. Battery string 508 comprising batteries 508a and 508b, is connected
7 between these DC voltage rails, as are capacitors 510a and 510b, which serve to
8 minimize voltage transients on the DC bus. Output inverter 511 also draws power from
9 or supplies power to the DC bus depending on the mode of operation.

10 Inverter 511 is the main output inverter and is designed to provide full output
11 power to the critical load connected at output 515. Output inverter 511 comprises two
12 switching devices, illustrated as power transistors 511a and 511b. In a three phase
13 system, a total of six power switching devices would be used, two for each phase.
14 Inverter 511 keeps the output voltage stable and regulated, whether the system is running
15 on AC power from input 501 or DC power from battery 508. If the AC power supplied at
16 input 501 is within the appropriate tolerances for the critical load, then inverter 511 is
17 unloaded. Inverter 511 is operated to produce an acceptable voltage, and injects power
18 and/or correction current to the UPS system bus through inductor 512, which serve to
19 smooth the current supplied to the output. Design of such inverters and their controllers
20 is well known to those of skill in the art.

21 When the input lines fail, it becomes necessary to disconnect the UPS from the
22 input lines to prevent power generated by inverter 511 from backfeeding the faulted
23 utility through UPS input 501. This is necessary to prevent: (1) the safety hazard that

1 would be presented by energizing the faulted input lines, (2) the disruption to the critical
2 load caused by being connected to the faulted lines, and (3) damage to or destruction of
3 various UPS components, including fuses (not shown) contained in output inverter 511.
4 When the utility disconnect switch 502 is naturally commutated, *e.g.*, is constructed with
5 SCRs, the voltage collapse at input 501 associated with many types of faults in
6 combination with the voltage generated by output inverter 511 naturally causes the
7 switching devices 502a and 502b to commute. This is so because the voltage on the
8 UPS bus will be higher in magnitude than that on the faulted input line, thereby driving
9 the current through the SCR to zero.

10 However, for certain types of faults, as described above, the voltage at input 501
11 may increase in magnitude, thus preventing the natural commutation of the SCRs 502,
12 because the utility voltage is forcing the line current to increase in magnitude, rather than
13 approaching zero. If the magnitude of this fault is within the correction range of the
14 series inverter 507, it is possible for the series inverter to block the disturbance from
15 reaching the system output bus. The correction range of the series inverter is limited by
16 design, primarily due to economic and efficiency concerns. Therefore, in most
17 applications, input faults that cause transients outside the correction range of the series
18 inverter can be expected. To minimize the impact of this transient, the present invention
19 uses one or both of the inverters 507 and 511 to force commute the utility disconnect
20 switch. Without the ability to quickly open the input switch, the series inverter is
21 susceptible to output faults; that is, an output short will cause the input line voltage to be
22 imposed across the series inverter. This voltage may be greater than the rating of the

1 series inverter and may cause damage to it. A method of commutating static switch
2 thyristors using an inverter in a UPS is disclosed in U.S. Patent 4,782,241.

3 One method of commutating the utility disconnect is to use only the main inverter
4 411. When a fault is detected that causes the voltage at the input 501 to change such that
5 the line current will increase in magnitude, the main inverter controller commands the
6 main inverter switches to a state that applies a voltage that causes the inverter current to
7 approach the load current. When the inverter current equals the load current, line current
8 will have been forced to zero, and commutation will have been achieved. In practice, it is
9 only necessary for the controller to have knowledge of the direction of the line current
10 and to select the inverter switch that provides the same voltage polarity as the line current
11 polarity. Although the resulting voltage transient seen at output 515 is somewhat
12 extreme, the short duration required is such that the load is not disrupted. Nor should the
13 inverter experience overcurrent stress. Typical SCRs used for static switch applications
14 will commute and be capable of blocking applied voltage in a few hundreds of
15 microseconds.

16 The critical load disruption may also be minimized using only the series inverter
17 507. However, the limited ratings of series inverter 507 require that the fault be detected
18 early before the voltage at input 501 is out of the range in which the series inverter has
19 sufficient capacity to force commute the input SCRs. Another alternative for
20 minimizing disruption to the critical load is to use the series inverter at its maximum
21 capacity and make up the additional energy required to null the current flow through the
22 SCRs using the main inverter. Because the series inverter is also used to null the current

1 flow, the requirements on the main inverter are reduced, thereby reducing the output
2 voltage distortion seen by the critical load and likely providing faster commutation.

3 The fast utility disconnect may also be constructed using gate commutated
4 switching devices, such as power transistors. This alternative embodiment is illustrated
5 in Fig. 6. A gate commutated switching device differs from a naturally commutated
6 switching device in that the device may be turned off simply by removing the gate pulse.
7 Those skilled in the art recognize that a gate commutated switch may also be made using
8 SCRs employing forced commutation.

9 Because a gate commutated switch may be opened when current is flowing
10 through the device, it is usually necessary to add some type of clamping circuit to the
11 switch to prevent its destruction from interrupting the current. However, if the equivalent
12 inductance seen by the switching devices is sufficiently low, the switching devices can
13 safely interrupt the current without damage, and a clamping circuit is not required.

14 One possible clamping circuit is shown in Fig. 6, and comprises four diodes 601,
15 602, 603, and 604. Diodes 601 and 602 are connected between the input of the fast utility
16 disconnect and the DC bus. Diodes 603 and 604 are connected between the output of the
17 fast utility disconnect switch and the DC bus. The diodes are arranged such that a
18 voltage excursion greater than either the positive or negative DC bus voltage on either
19 side of the fast utility disconnect will be clamped to the DC bus voltage. The excess
20 energy from such a voltage excursion will be absorbed by the battery 508 and DC bus
21 capacitors 510a and 510b.

22 An alternative clamping circuit is shown in Fig. 7. The clamping circuit
23 comprises four diodes 701, 702, 703, and 704 and a capacitor 705. The principle of

1 operation is similar to that described above. Diodes 701 and 702 connect the input side
2 of the utility disconnect switch to capacitor 705, and diodes 703 and 704 connect the
3 output side of the utility disconnect switch to capacitor 705. During normal operation,
4 capacitor 705 will charge to the peak AC voltage supplied at input 501. If a larger
5 voltage is impressed on either side of the input static switch, as would be presented by the
6 interruption of the load current by the utility disconnect switch, the appropriate diode
7 begins to conduct and the excess energy associated with the voltage excursion is
8 absorbed by capacitor 705.

9 Another possible clamp for a self commutated fast utility disconnect in Fig. 9.
10 The clamping circuit comprises four diodes 901-904 and capacitor 905. The anode of
11 diode 901 is coupled to the input side of the fast utility disconnect 906, and the cathode is
12 coupled to a first terminal of capacitor 905. Similarly, the cathode of diode 903 is
13 coupled to the input side of fast utility disconnect 906, with the anode coupled to a
14 second terminal of capacitor 905. Diode 902 has its cathode coupled to the first terminal
15 of capacitor 905 and its anode coupled to ground, while diode 904 has its anode coupled
16 to the second terminal of capacitor 905 and its cathode coupled to ground. In operation, a
17 transient voltage excursion at the input side of fast utility disconnect 906 will cause diode
18 901 (for positive voltage excursions) or diode 902 (for negative voltage excursions) to
19 conduct and allowing capacitor 905 to absorb the energy of the transient voltage
20 excursion, and excess energy is dissipated to ground through diodes 904 (for positive
21 voltage excursions) or diode 902 (for negative voltage excursions).

22 Another clamping circuit for use with a self-commutated fast utility disconnect
23 switch is illustrated in Fig. 10. The clamping circuit is connected to the input side of fast

1 utility disconnect 1001 and comprises diodes 1002 and 1003 and capacitors 1004 and
 2 1005. Diode 1002 has its anode coupled to the input side of fast utility disconnect 1001
 3 and its cathode coupled to a first terminal of capacitor 1004. Similarly diode 1003 has its
 4 cathode coupled to the input side of fast utility disconnect 1001 and its anode coupled to
 5 a second terminal of capacitor 1005. The second terminal of capacitor 1004 and the first
 6 terminal of capacitor 1005 are coupled together and are coupled to ground. In the event
 7 of a transient voltage excursion associated with the inductive reactance of the power line
 8 circuit and caused by commutation of the fast utility disconnect, diode 1002 (for positive
 9 voltage excursions) or diode 1003 (for negative voltage excursions) will conduct
 10 allowing capacitor 1004 or 1005 respectively to absorb the energy associated with the
 11 transient voltage excursion.

12 Finally, another clamping circuit for use with a self commutated fast utility
 13 disconnect is illustrated in Fig. 11. The clamping circuit comprises two voltage limiting
 14 diodes 1101 and 1102 connected to the input side of fast utility disconnect 1103. The
 15 cathode of voltage limiting diode 1101 is coupled to the input of fast utility disconnect
 16 1103, with the anode being coupled to the anode of voltage limiting diode 1102. The
 17 cathode of voltage limiting diode 1102 is coupled to ground, allowing either positive or
 18 negative transient voltage excursions to be sunk to ground.

19 The voltage limiting diodes 1101 and 1002 could be replaced with any other bi-
 20 directional transient voltage suppression device, for example, varistors, including metal
 21 oxide varistors, back-to-back transorbs, breakdown diodes (Shockley diodes, diacs),
 22 carbon piles, gas discharge devices, etc.

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1 To force or assist commutation of the static switch, it is necessary to know the
2 direction of the current flowing through the static switch. One way of determining the
3 current direction is to use a current sensor that produces an analog signal. Connection of
4 such a sensor 801 is illustrated in Fig. 8. Alternatively, the direction of the current can be
5 determined by observing the voltage across the static switch. Connection of the required
6 voltage sensor 802 is also illustrated in Fig. 8. The voltage sensor technique is preferred,
7 as it is less sensitive to offset errors.

8 Additional modifications and adaptations of the present invention will be obvious
9 to one of ordinary skill in the art, and it is understood that the invention is not to be
10 limited to the particular illustrative embodiments set forth herein. It is intended that the
11 invention embrace all such modified forms as come within the scope of the following
12 claims.

REFERENCES

The following references, to the extent that they provide exemplary procedural or other details supplementary to those set forth herein, are specifically incorporated herein by reference.

U.S. Patent No. 4,782,241, entitled "Uninterruptible Power Supply Apparatus and Power Path Transfer Method."

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SEQUENCE LISTING

- 1
- 2 Not Applicable

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